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NOTES ON THE PRIVATE AND SOCIAL VALUE OF INFORMATION

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22

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22

NOTES ON THE PRIVATE AND SOCIAL VALUE OF INFORMATION

Recent articles on the "economics of information" have been addressed to the problem of the acquisition and dissemination of information about existing market opportunities.[1] In these articles each individual's endowment and productive opportunities, giving rise to his supply-demand offers, are assumed to be fully known to the individual himself. The problem is that markets are imperfect, the individual's offers being less than fully known to all other individuals. Consequently, costly efforts on the part of buyers and sellers to search for trading partners replace the traditional costless functioning of perfect markets.

In these notes I will examine quite a different sort of "economics of information". I hold to the textbook assumption that markets are perfect and costless, that an equilibrium integrating all individuals' supply-demand offers is attained instantaneously. Uncertainty, or lack of information, exists because every individual is unsure about the size of his own endowment and/or the returns he will attain from his own productive investments. The basis of this uncertainty is typically not ignorance as to the actual state of affairs at this date, but rather uncertainty as to events that have not yet occurred: e.g., will we have next year a good harvest or a bad one?[2]

The analysis runs in terms of a model incorporating both temporality and uncertainty. There is a single physical good

("corn"), but a number of different claims may be owned or traded -- claims to corn at specified dates and under specified contingencies or "states".[3] It will be sufficient to consider a particularly simple paradigm in which the present (time-0) is certain, and the future consists of a single date (time-1) at which just one of two alternative states (a or b) will obtain. The commodities of our analysis can then be denoted c_0, c_{1a}, and c_{1b} -- claims to corn at the respective dates and states.

Each individual will have a utility function governing his preferences now for holdings of alternative combinations of these claims. Under some plausible though special assumptions (see below), this utility function can be expressed in the following form:

$$(1) \qquad u = v_0 + \theta\,(\pi_a\, v_{1a} + \pi_b\, v_{1b})\ .$$

Here v_0, the component of utility attributable to consumption at t=0, is assumed to be independent of the amounts scheduled for consumption under the contingencies at t=1; similarly, v_{1a} depends only on c_{1a}, and v_{1b} only on c_{1b}. The symbol θ may be regarded as a time-preference parameter. The (subjective) probabilities π_a and π_b enter in the way dictated by the Neumann-Morgenstern "expected utility rule". This would perhaps be clearer if the function were written:

$$(1a) \qquad u = \pi_a(v_0+\theta v_{1a}) + \pi_b(v_0+\theta v_{1b})\,.$$

"Information" will take the form of revisions in these probability estimates. A utility function of the form (1) or (1a) may be

said to display both time-independence and state-indepencence.[4]

In what follows private information (that available to but a single individual) will be distinguished from public information (that available to everyone) -- ignoring all intermediate cases. It will also be important to keep in mind the distinction between information that is prior to, and information that is posterior to, the consumption-investment decisions that must be made at t=0. Posterior information, while in general less valuable than prior information, will still be of considerable worth so long as exchanges between c_{1a}-claims and c_{1b}-claims are still taking place -- i.e., so long as the event "occurrence of state-a" or "occurrence of state-b" has not become public knowledge. Attention will be centered upon the gains from possession of sure information as to which state will obtain. Occasional remarks will be made as to the benefits of merely better information -- that is, of a sharper focusing of subjective probabilities that does not entirely eliminate uncertainty.

A. PURE EXCHANGE

For concreteness, we will consider a particular numerical example -- first under a regime of pure exchange, and then under a regime in which production as well as exchange may take place. Let us suppose, then, a competitive world of pure exchange in which every individual's endowment as distributed over dates and states, is identical : to wit, y_0=100, y_{1a}=200, and y_{1b}=80. We assume further that the utility functions are

identical for all individuals, taking the specific form $v = \log_e c$ for each time-state, with the time-preference parameter θ equal to unity and with probability beliefs $\pi_a = .6$ and $\pi_b = .4$. Evidently, the price structure that will emerge must "sustain" the endowment pattern (i.e., must assure that each "representative individual" will desire to hold the exact quantities of y_0, y_{1a}, and y_{1b} with which he is endowed). Taking c_0 as mumeraire so that $P_0 = 1$, we obtain the numerical solution $P_{1a} = .3$ and $P_{1b} = .5$.[5] The individual's wealth -- the market value of his endowment -- will be $P_0 y_0 + P_{1a} y_{1a} + P_{1b} y_{1b} = 100 + .3(22) + .5(80)$, or 200 in c^0-units, while his utility u will be 9.5370 (see Table 1). This is the base situation with which the results of changes in the information (or knowledge or beliefs) possessed by individuals in the market will be compared.

Suppose that at time-0 a single individual has prior, private, and sure information that state-a will obtain at time-1. Since the individual's choices would only negligibly affect the ruling prices $P_{1a} = .3$ and $P_{1b} = .5$, he could realize the full present value $P_{1b} y_{1b} = .5(80) = 40$ of the c_{1b}-endowment (that he alone knows to be worthless) -- for reallocation to the purchase of more c_0 and/or c_{1a}. Table 1 indicates that he will actually purchase just $40/P_{1a} = 133.3$ units of c_{1a} (to add to his endowed 200 units). Similarly, if he knew in advance that state-b would obtain, he would reallocate the entire value $P_{1a} y_{1a} = 60$ of his c_{1a}-endowment so as to purchase $60/P_{1b} = 120$

units of c_{1b}. That these adjustments are indeed optimal can be shown by the usual Lagrangean multiplier technique.[6]

It may seem surprising that none of the individual's wealth that is freed (in consequence of obtaining the sure information as to which one of the future states will obtain), by elimination of the necessity to "cover" the other contingency, is reallocated as to increase current consumption c_0. Indeed, in the circumstances of this example, inform ation that is prior to the consumption-investment decision at t=0 is no more valuable than information that is posterior to that decision;[7] with or without the prior information, the individual's current consumption remains c_0=100. In ordinary price theory we would expect -- in a comparable situation where consumptive expenditures previously distributed over 3 commodities are now concentrated on 2 -- to observe an increase in the quantitites purchased of both of the remaining commodities. Exceptions might occur if one of the commodities remaining were either an inferior good, or were highly complementary with the commodity no longer purchased. Neither of these exceptions is applicable here: with the specified utility function, all of the consumptive claims are superior goods, and there are no complementarity relations among them.[8] The analogy is not appropriate, however. What the individual is reacting to is not a simple increase in funds available for spending on c_0 and/or c_{1a}, but rather such an increase combined with a sharp jump in the entire utility component π_a v_{1a} attributed to c_{1a}.

The exact result obtained in this example, that optimal current consumption remains entirely unaffected at $c_0=100$ while c_{1a} rises from 200 to 333.3, is however a special case. More generally, with utility functions in the state-independent and time-independent form (1), but allowing any function of the usual properties in place of $\log_e c$ for $v(c)$, the following result is obtained (proof omitted): c_0 will increase, remain unchanged, or decrease according to whether $v_1' c_1$ is a decreasing, constant, or increasing function of c_1.[9] Evidently then, the special case of unchanged c_0 is not an abnormal or extreme result.

Consider now the worth to the individual of sure private information as to the future state. Given that the information is that state-a will obtain, we see in Table 1 that expected utility has risen from 9.5370 to 10.4143. Note how enormous this increment is in comparison with, say, the marginal utility of c_0 (equal to just .01 when $c_0=100$). The individual could not have known in advance, however, that the information would point to the occurrence of state-a. Had it indicated instead that state-b would obtain, expected-utility would have risen from 9.5370 to only 9.9035. Since *a priori* the individual would have had to assign probability .6 that the information would point to state-a, and .4 that it would point to state-b, his expected utility given perfect information (as calculated in advance) is 10.2100. It is evident that it would pay the individual to sacrifice (invest) a considerable amount for this

information. It would of course be possible to generalize this result to show the value of less-than-perfect information: for example, of evidence that would warrant assigning 90% instead of 100% probability to one or the other state.

What of the _social_ value of the sure information just analyzed above? Suppose that by a collective payment to some knowledgeable outsider, an entire community consisting of the representative individuals above could simultanesously be informed as to which future state will obtain -- how large a payment would then be justified? It is evident that such information would be _absolutely valueless_ to the community as a whole. Information is of value only if it can affect action. But with identical endowments, preferences, and beliefs in a world of pure exchange, all individuals must still end up holding their endowment time-state distributions. The only thing to happen given the information is that prices would shift immediately to permit "sustaining" the endowment vector, in the face of the change in beliefs that enter into the utility function (1). It may be verified that sure public information that state-_a_ will obtain, available _prior_ to the consumption-investment decisions at t=0, will cause P_{1a} to rise to .5 (while P_{1b}, of course, falls to zero). Sure public prior information that state-_b_ will obtain raises P_{1b} to 1.25, while P_{1a} falls to zero. Table 2 confirms that the expected utility of having perfect public information is no different from the expected utility under uncertainty.

There is a possibility of still greater private gain for the knowledgeable individual if he can speculate rather than merely move to his preferred consumptive position. Assuming private knowledge that state-a was to obtain, a speculating individual would conceivably convert all of his initial wealth to c_{1a}-holdings at the old price relationships. In the ideal case, the true information would then become public still prior to the finalizing of the consumption-investment decisions at t=0. Note that the individual with private information would have every incentive to publicize that information after making his speculative commitment -- since he will have to liquidate a portion of his commitment in time to meet his needs for c_0-consumption. Quantitatively, the individual's wealth of 200 would buy 200/.3 = 666.7 units of c_{1a} at the original price P_{1a}=.3. Upon the information becoming public P_{1a} will jump to .5 so that the individual will now be in possession of a wealth of 333.3 -- permitting him to obtain the combination c_0=166.7, c_{1a}=333.3. Again, however, the community as a whole obtains no benefit from either the acquisition or the dissemination of the information.

Any sacrifice of real resources, for the acquisition or the dissemination of the type of information here considered, is thus socially wasteful under pure exchange.[10] But, evidently, every individual will have a very great incentive to acquire private knowledge for consumptive and possibly speculative purposes. After acquiring the information, any individual having adopted a speculative position will also have a great

incentive to disseminate that information. Since the acquisition and the dissemination will, in general, require some investment of real resources, we obtain the surprising result that there tends to be private <u>over</u>-investment in the acquisition and dissemination of information.

The result seems surprising because information is widely considered to be one of the classic types of "collective good", the type of commodity for which private incentives lead to under-provision rather than over-provision on the market. Indeed, there is something of a collective-good aspect to information given the sort of uncertainty model alluded to earlier -- where information helps improve otherwise imperfect markets. Here, however, the expenditure of real resources for the production of information is socially wasteful -- as the expenditure of resources for an increase in the quantity of money (e.g., by mining gold) is wasteful, and for essentially the same reason. Just as a smaller quantity of money serves monetary functions as well as a larger, the price level adjusting correspondingly, so a larger amount of information serves no social purpose under pure exchange that the smaller amount did not.

B. PRODUCTION AND EXCHANGE

Consider now the value of private and public information in a regime in which production and exchange can both take place. Assume that endowments are just the same as before, for all individuals. But suppose that, in addition, every

individual has a small discrete productive opportunity of the following form: exactly 1 unit of endowed c_0 may be sacrificed to produce additional income in either time-state <u>1a</u> or time-state <u>1b</u> (but not both). That is, each individual can choose to invest at t=0, while still ignorant as to which state will obtain at t=1, so as to reap a return in one state <u>or</u> the other. Given that P_{1a}=.3 and P_{1b}=.5 in advance of the production decisions, marginal investments paying off in state-<u>a</u> will be profitable if they yield more than 3.3 units of c_{1a}; marginal investments paying off in state-<u>b</u> will be profitable if they yield more than 2 units of c_{1b}. Let us suppose that the opportunities available permit choosing between 2½ units in state-<u>a</u> and 2½ units in state-<u>b</u>. Under uncertainty, every investor would choose the latter, converting his endowment combination (y_0=100, y_{1a}=200,y_{1b}=80) into the produced combination (c_0=99, c_{1a}=200, c_{1b}=82.5). (Since the scale of the investment is not infinitesimal, the prices change slightly -- but not by enough to modify the desirability of the investment.[11])

Suppose now that one individual is given sure prior private information that state-<u>b</u> will obtain. Evidently, this would make no difference in his personal productive decision; even under undertainty he will have chosen to invest in favor of c_{1b}. Setting aside for the moment the possibility of making <u>speculative</u> commitments, the individual would respond to this information only by disposing immediately of his

endowed c_{1a}-holdings at their current market values. What if the private information is that state-a will obtain? Here it would be socially desirable that this individual's sacrifice of c_0 (and everyone else's, as well) be redirected so as to produce c_{1a} instead of c_{1b}. But if the information is private the original prices must still be ruling, so that the individual's incentives for production decisions remain unchanged. He will continue to invest for a c_{1b}-return, even knowing that the latter will become valueless. But he will hav arranged in advance to liquidate the added 2½ units of c_{1b}, in addition to his endowed 80 units, at the ruling market prices. Thus, as under the regime of pure exchange, private information makes possible large private profit without leading to socially useful activity. The individual would have just as much incentive as under pure exchange (even more, in fact) to expend real resources in generating socially useless private information.

What of the value of public information? Given the information that state-b will obtain, there would evidently be no change in the productive decisions (to invest in favor of c_{1b}) that were taken under uncertainty. We know that P_{1b} would in fact jump to 1.25 (in advance of the productive commitments), P_{1a} falling to zero, so that a sacrifice of one unit of c_0 for 2½ of c_{1b} would become highly profitable. On the other hand, if the information were that state-a would obtain, P_{1a} would jump to .5 (P_{1b} falling to zero). Then the individual investments would all be shifted so as to yield c_{1a} instead of c_{1b}.

So public information as to which state will obtain __is__ of social value in a regime of production and exchange.

However, it remains true that the value of private information is enormously greater to any individual than the value of public information. In the example used here, public information enables the representative individual to attain with probability .6 the time-distribution (c_0=99, c_1=202.5), or with probability .4 the distribution (c_0=99, c_1=82.5). Private information enables him to attain with probability .6 the combination (c_0=99, c_1=337.5) -- based on converting his 82.5 units of c_{1b} at the original price ratio into 137.5 units units of c_{1a} to be added to his endowed 200 units -- or with probability .4 the combination (c_0=99, c_1=202.5). Evidently, the possibilities with private information are far superior (still leaving aside the prospect of still greater gains through speculative commitments). Thus, enormous incentives remain for the socially unproductive use of resources to generate private information.

C. SOME IMPLICATIONS

These results certainly seem surprising. The very sort of researches to which a large fraction of our progress is usually attributed -- for example, privately motivated investigations into the properties of alloys, drugs, and processes -- constitute just such attempts to generate private information. The thought that market forces cause such

investigations to be pressed at a rate greater than would be socially optimal is perhaps not unheard-of, but certainly not a common opinion.

There is, however, one element that remains to be considered: speculation. It will be recalled that, having undertaken a speculative commitment, it was in the interest of the possessor of private information to go ahead and publicize it. Under pure exchange, where information is socially valueless, efforts at dissemination represented only an additional source of social waste. Under a regime of production and exchange, however, timely publication of information -- in advance of investment commitments -- can indeed be socially useful. Without closer specification of the private and social costs of the processes for gathering and disseminating information, we cannot conclusively determine whether the overall result is socially wasteful or not. However, in view of the open-ended nature of the benefit from dissemination (that an indefinitely large number of individuals can benefit from public information) and the limited costs involved, we may perhaps presume that there will typically be a net social advantage attached to private efforts in this direction.

Thus our analysis suggests that while private processes for generating information tend to be pushed beyond what is socially ideal, the reverse very likely holds when it comes to the dissemination of information. Thus patent policy, which

awards a benefit for new information conditionalupon dissemination, would seem to be supported by these considerations. A subsidy for industrial espionage might also be wise public policy.

TABLE I

Private Value of Information

	CONSUMPTIVE CHOICES			UTILITY [a]		
	Uncert-ainty	State-a to obtain	State-b to obtain	Uncert-ainty [b]	State-a to obtain [c]	State-b to obtain [d]
c_0	100	100	100	4.6052	4.6052	4.6052
c_{1a}	200	333.3	-	.6(5.2983)	5.8091	-
c_{1b}	80	-	200	.4(4.3821)	-	5.2983
		Expected Utility		9.5370	10.4143	9.9035

Expected Utility given perfect information: 10.2100

a Computed according to: $u = \log_e c_0 + \pi_a \log_e c_{1a} + \pi_b \log_e c_{1b}$.

b $\pi_a = .6$, $\pi_b = .4$

c $\pi_a = 1$, $\pi_b = 0$

d $\pi_a = 0$, $\pi_b = 1$

TABLE 2
SOCIAL VALUE OF INFORMATION

	CONSUMPTIVE CHOICES			UTILITY		
	Uncertainty	State-a to obtain	State-b to obtain	Uncertainty	State-a to obtain	State-b to obtain
c_0	100	100	100	4.6052	4.6052	4.6052
c_{1a}	200	200	-	.6(5.2983)	5.2983	-
c_{1b}	80	-	80	.4(4.3821)	-	4.3821
		Expected Utility:		9.5370	9.9035	8.9873

Expected Utility given perfect information: 9.5370

FOOTNOTES

1. S. A. Ozga, "Imperfect Markets through Lack of Knowledge," QJE, February 1960; G. Stigler, "The Economics of Information," JPE June 1961, and "Information in the Labor Market," JPE October 1962 (Supplement).

2. The distinction between these two types of uncertainty has been made before: see T. Koopmans, THREE ESSAYS ON THE STATE OF ECONOMIC SCIENCE (McGraw-Hill, 1957), pp. 161ff.

3. This is called a <u>time-state preference structure</u> in my "Investment Decision under Uncertainty -- Choice-Theoretic Approaches," QJE November 1965. It is a natural generalization of Irving Fisher's intertemporal model to the domain of uncertainty. The conception of state-claims as commodities stems from the pioneering work of Kenneth J. Arrow, "Le Role des Valeurs Boursieres pour la Repartition la Meilleure des Risques," <u>International Colloquium on Econometrics, 1952</u>, Centre National de la Recherche Scientifique (Paris, 1953). An English translation appeared under the title "The Role of Securities in the Optimal Allocation of Risk-Bearing," <u>Review of Economic Studies</u>, v. 31 (April, 1964). G. Debreu extended this model to multiple time-periods in his THEORY OF VALUE (New York: Wiley, 1959), Ch. 7.

4. <u>State-independence</u> is the Neumann-Morgenstern postulate sometimes known as "independence of beliefs and rewards" (see J. Marschak, "Decision-Making: Economic Aspects," prepared for <u>International Encyclopedia of the Social Sciences</u>). The key idea is that when we are dealing with <u>prospects</u>, which promise to offer one consequence if state-<u>a</u> obtains and another if state-<u>b</u> obtains, we need not consider any relations of (positive or negative) complementarity in preference. For, there is never a question of receiving the <u>combined</u> consequences attached to the two states; we will necessarily receive one to the exclusion of the other. <u>Time-independence</u>, absence of complementarity in preference between consequences at t=0 and consequences at t=1, does not have so powerful a justification, for we will indeed receive a combination of consequences over time). The assumption may be accepted as a simplification; in the absence of any compelling reason to anticipate that the time-complementarities are either positive or negative, the assumption of zero complementarity may be a satisfactory approximation.

5. The individual maximizes $u = \log_e c_0 + \pi_a \log_e c_{1a} + \pi_b \log_e c_{1b}$
$= \log_e c_0 c_{1a}^{.6} c_{1b}^{.4}$,

subject to:

$$p_0 c_0 + p_{1a} c_{1a} + p_{1b} c_{1b} = p_0 y_0 = p_0 y_0 + p_{1a} y_{1a} + p_{1b} y_{1b}.$$

The usual Lagrangean conditions lead to:

$$\frac{1}{c_0} = \lambda p_0 \ , \quad \frac{\pi_a}{c_{1a}} = \lambda p_{1a} \ , \quad \frac{\pi_b}{c_{1b}} = \lambda p_{1b} \ .$$

Given that $p_0=1$, and that (since all individuals have identical preferences and opportunities) $c_0=y_0$, $c_{1a}=y_{1a}$, and $c_{1b}=y_{1b}$, we obtain $p_{1a} = \frac{.6\ y_0}{y_{1a}} = .3$,

$$p_{1b} = \frac{.4\ y_0}{y_{1a}} = \frac{.4\ y_0}{y_{1b}} = .5 \quad .$$

6. Knowing that state-a will obtain, the individual will attempt to maximize $u=\log_e c_0 c_{1a}$ (that is, the expected utility with $\pi_a=1$ and $\pi_b=0$) subject to $c_0+p_{1a}c_{1a}+ p_{1b}c_{1b} = y_0+p_{1a}y_{1a}+ p_{1b}y_{1b} = 200$. The resulting condition is $c_0=p_{1a}c_{1a}$ which, combined with the constraint, dictates that $c_0=100$ and $c_{1a}=333.3$. The result for state-b is obtained similarly.

7. At t=1, but before it is revealed which state has obtained, the ratio of the prices p_{1a} and p_{1b} would still be 3/5.

   The no-longer-desired claim could still be exchanged for the other at the same ratio as that effective at t=0.

8. That is, the utility cross-derivatives are all zero.

9. In the numerical example here, $v_1=\log_e c_1$ so that $v_1'=1/c_1$ -- hence $v_1'c_1=1$, a constant.

10. If the pure-exchange regime (absence of any possibility for productive sacrifice of c_0 for increments in c_{1a} and/or c_{1b}) is not inconsistent with the sacrifice of real resources for "production" of information or its dissemination, such real sacrifices could take place.

11. It may be verified that the ruling prices will become P_{1a}=.297, P_{1b} = .480. Prices of both future claims fall because of the greater scarcity of c_0 -- P_{1b} falling more because, in addition, c_{1b} is more plentiful.

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13 ABSTRACT Recent research on the 'economics of information" has examined the acquisition and dissemination of information in a context where uncertainty attaches to the supply-demand offers of potential market partners. In this paper markets are assumed to be perfect, and uncertainty is attached to each individual's perception of his own endowment and productive opportunities. The private and public values of pure prior information are compared where individuals aim to distribute their consumption optimally over dates and states. Under pure exchange, information as to which future state will obtain is generally of enormous private value but of no social value; hence there is an incentive for individuals to expend resources in a socially wasteful way to generate and disseminate this information. In a world of production and exchange these results are modified somewhat, since prior public information will affect production decisions in the appropriate way. It is shown that there still remains a bias, suggesting that private investigations into the question of which state does or will obtain (e.g., private scientific research) are carried beyond what is socially optimal. On the other hand, there is a strong presumption that the dissemination of information will be socially valuable. Thus, the government should support industrial research less but industrial espionage more!

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14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.